

## Development of the Hy-Score Air Pistol

### *History*

About the year 1940 after several years of research work, mostly in applied mechanics, I found myself at loose ends and looking around for practical things to do. After I had spent some months designing, among other things, overhead garage doors and pumps for windshield wipers, my brother, who was in the sporting goods importing business, suggested that I should spend some thought to develop a modern high powered air pistol.

In this country at that time there were only two air pistols which could be considered as high powered on the market, both of them pump style. In principle these guns rely on manually compressing air into a reservoir from which it is subsequently released thru a valve and caused to

expel a pellet. The pellets are made of soft lead and come in two calibers, .177 and .22.

In order to obtain the desired minimum muzzle velocity of about 400 ft/sec for cal.177 and 300 ft/sec for cal.22, one must pump these guns from eight to twelve times, a pretty tiring matter. On top of that the valve sealing the reservoir is subject to bothersome leaks. True enough, one can pump up the gun even more than that and get considerably higher muzzle velocity, but for target shooting the power, hence the number of pumpings, must be uniform and to pump the gun say 150 times for ten shots is not very conducive to steady hands. This is the main reason for the later appearance of the CO<sub>2</sub> cartridge guns on the market.

As can be readily seen pump guns are

inherently inefficient, operating on an isothermic compression cycle with nearly all compression heat lost thru conduction.

In contrast European manufacturers of air pistols concentrated on spring type guns. In these the air is adiabatically compressed by a spring-actuated piston and simultaneously led behind the pellet to do its work. As a consequence only one cocking action is required, while compressing the spring prior to shooting. Because of the adiabatic compression these guns can be far more efficient than pump guns. Because of the powerful spring needed, there is an appreciable recoil action lacking in pump guns. Still, for those who use air pistols as a substitute for fire arms, the recoil is an advantage.

The cocking of the spring is achieved in a number of ways and here is where the ingenuity of the designer has its full sway. One must say, however, that most of the air guns were designed by people raised in the gunsmith's tradition, burdened by traditional thinking, all too obvious in the use of forged, milled and profiled parts. A new approach was indicated.

### *Conception*

In order to get our feet on the ground we purchased a number of European air pistols to serve as objects of study. Four of these were fairly representative and I propose to discuss them; two of them were German, one British, one Swedish.

The German Diana pistol (Exhibit 1) has a hinged barrel to which a lever is attached. The rear end of the lever is in contact with a spring loaded piston. By rotating the barrel downward thru an angle

of about  $90^{\circ}$ , the lever pushes the piston rearward until the latter engages a sear. While in this position the breech end of the barrel is exposed for loading, after which the barrel is returned to its shooting position where the breech abutts against a leather washer acting as an air seal. The air chamber and breech are connected by a small drilled hole. No valve is necessary as is true of all spring type guns.

The general arrangement of air chamber and barrel of the Haenel pistol (Exhibit 2) is similar to Diana's, except that the cocking is done by a rearward rotation of the pistol grip. To the grip is attached a short lever which engages the piston and causes it to move back while cocking. Note the limited angular rotation of the grip amounting to less than  $60^{\circ}$ .

The Swedish Zenit gun (Exhibit 3) overcomes this limitation by arranging a separate cocking lever on top of the spring housing. This hinges at the front and is attached to a piston actuating lever same as Diana. This permits much larger angular movement for the cocking action than either of the first two.

Note that all three guns have the barrel in front of the spring chamber and that the piston travels forward during firing.

By contrast the British Webley (Exhibit 4) carries the barrel on top of the spring housing. Cocking is done by gripping the barrel, which is hinged at the front, and swinging it forward thru an arc of about  $180^{\circ}$ . This pulls the piston forward by means of a link. Being in tension the link can be much lighter than the compression levers used in the first three. After loading

the barrel is returned and locked in position by a stirup. The breech sealing on all four guns is done by leather seals which of course need periodic replacement. Note that in the Webley gun the piston travels backward during firing, hence the air reverses direction passing from air cylinder to the barrel.

An analysis of these pistols brought to light the following observations. Cocking of the Diana with its 7" barrel length was relatively easy but its power was less than was considered desirable. In addition the overall length was excessive, making it muzzle heavy and awkward looking.

The Haenel had a shorter barrel and better appearance, but was very hard to cock and its power inferior to Diana's.

The Zenit gun was the easiest to cock as was to be expected. Unfortunately because of its shorter barrel and lighter spring its power was quite poor.

Of the four guns the Webley came closest to the ideal from point of view of ease of cocking and most power. In target testing, however, it proved to be a difficult gun to use because of its high trigger pull. In fact all four had trigger pulls ranging from five to ten pounds, whereas the ideal should be between three and four.

With the exception of Webley all guns had leather piston seals, Webley using a bronze split piston ring.

From a manufacturing point of view only the Zenit made more extensive use of stampings in lieu of machined parts.

### *Design*

It became fairly obvious in the course of this study that in order to come up with a commercially saleable high powered air pistol, the following design guide lines had to be followed:

1. Ease of cocking
2. Minimum muzzle velocity of 300, resp. 400 ft/sec for the two calibers.
3. Elimination of parts needing frequent replacements such as leather, etc.
4. Trigger pull not to exceed 3½ pounds and to be short and crisp.
5. Barrel to be rifled for accuracy.
6. Appearance and balance to approximate as closely as possible that of a standard firearm.
7. Low manufacturing cost by use of stampings, automatic screw machine parts and plastics.

The first point dictates a long lever arm swinging thru a large angle.

For maximum power a long barrel is needed, as well as a strong spring and minimum air loss thru leakage.

Point three calls for metallic seals.

The fourth point called for a reduction of friction between piston and sear and if this is not sufficient, then the possible use of some sort of servo mechanism.

Point five was obvious; in fact all four guns used rifled barrels both for power and accuracy.

Point six set an approximate limit of about 10 inch overall length and a weight of about two pounds.

The seventh point implied a high tooling cost in dies and molds with the

hope of these being amortized in quantity production. It also meant an early freezing of the design for the same reason.

Webley and Zenit both met the first requirement, but, as mentioned before, the latter had poor power, while Webley had an unconventional appearance, in addition to which its thin barrel showed signs of bending while being cocked. Thus a new design, incorporating as many of the desirable features as possible, was indicated.

### *The Hy-Score Design*

The idea presented itself to place the barrel concentrically inside the spring housing and piston and swing the entire unit thus formed around a pivot point placed well forward on a frame (Exhibit 5).

This at one stroke solved the problem of easy cocking as well as high power. The barrel assembly could be swung thru an arc of over 130° and the length of the barrel could be as large as the gun itself, provided a suitable breech closure could be devised. As an extra bonus the appearance of the gun was vastly improved.

Considerations of appearance as well as cost dictated a one inch diameter for the outside of the spring housing and a piston stroke of approximately 2¼ in. Calculation showed that within these limitations the strongest round wire spring which could be accommodated in the available space was about 90 to 100 pounds in the fully compressed state. Greater energy storage could have been obtained by using rectangular wire section, but the cost of such a spring is several times higher than that of a conventional one.

The angular rotation of the barrel assembly was limited to about 130° by the muzzle getting close to the trigger guard in the extreme cocked position. This fixed the approximate position of the main pivot point. The resulting appearance was much the same as that of the Colt Woodsman target firearm.

The location of the pivot point, piston stroke, and angular rotation predetermined the size and location of the cocking linkage.

The one obvious drawback was the additional leakage and sealing problem created by the fact that the barrel must go through the piston. This required later development work.

The breech closure was achieved by a novel shutter design (Exhibit 6). The rear closure of the air chamber is threaded on the outside over which fits a cap "A" which has a suitable opening in the back for dropping the pellets through. The cap has a recess inside accomodating a teaser spring "B" which in turn engages a projection on shutter plate "C". The latter is pivoted in rear closure "D". When the cap is rotated counter clockwise the shutter swings to the left exposing the breech opening for loading. When the cap turns clockwise, the shutter swings back to cover up the breech. A further tightening of the cap clamps the shutter tightly against an angular ring on closure "D" thus acting as a seal. Air passage is assured through a narrow annular gap between the barrel and closure "D" and a gap between shutter and end of barrel.

For sealing the piston in the cylinder a standard split piston ring was decided on.

The requirement for light trigger pull was a knotty one to solve. The main spring pressure is about 90 to 100 pounds in the cocked position, hence the frictional force on the sear is substantial. If the trigger bears directly on the sear, a high trigger pull is unavoidable, especially when it must also be short and crisp. A servo mechanism was thus indicated and eventually the design shown on Exhibit 7 was adopted.

The trigger "A" is hinged at "B" which also serves as a pivot for servo lever "C". This U shaped lever is forced upward by a spring "D" by a force of about 10 pounds. After cocking the gun and in the act of closing the bracket "F" carrying the sear, forces the servo lever down, compressing this spring. The lever is slotted at point "B" so that when the trigger is pulled, it can slide laterally. After a short travel of about .040 in. it slides off the edge of the sear bracket, when spring "D" forces it up to hit the sear "E". It can be readily seen that the trigger has merely to overcome the friction created by a 10 pound spring instead of the main spring.

For economy of manufacture I decided on a two piece molded Tenite handle, cemented together. This performed multiple functions in being able to position other elements, in addition to which it carried two heavy steel slugs molded in place to improve the balance of the gun. The main housing was of seamless steel tubing, suitably slotted, to which a muzzle made of screw machine part was copper brazed. (Exhibit 8)

#### *Development*

During this stage a number of details had to be solved. The copper brazed two piece construction was soon replaced by a

one piece design, rotary swaged in front out of a tubing and flattened on two sides at front to take the main hinge pin. It was counter bored at front (Exhibit 11) to anchor the barrel carrying a collar. The collar is flanked on both sides by neoprene rings for cushioning and the assembly held in place by crimping the muzzle over it.

In order to avoid possible binding of the piston on the barrel, the latter was left floating. In effect it is the piston which supports it.

The metal piston ring was found too brittle to withstand the shock of firing and was replaced by a neoprene O ring which proved highly dependable as well as cheaper. In addition it eliminated a costly honing operation on the cylinder bore, a necessity with metal rings.

A similar O ring seal was tried between piston and barrel but was dropped in favor of a close sliding fit of about .001. This proved to be quite adequate provided the gun was periodically lubricated by a few drops of oil.

The annular seal between shutter and rear closure was made first of hard rubber. This was so brittle that it was soon dropped in favor of an integral metal projection on the closure machined to a smooth finish. Note the gradual abandonment of all vulnerable parts in favor of permanent structures.

The size of the annular air passage between barrel and rear closure turned out to be critical. If too large, the air went through unhindered and in repeated blank firing with no pellet in the breech, the hammering action of the piston soon shook the gun to pieces. By reducing the size of

the passage to about .010 in. an air cushion was created, effectively safe-guarding the gun without reduction of power.

The barrel was made of seamless steel tubing. This was button rifled by pulling thru a suitably shaped tool carrying small spiral grooves which formed the rifling by cold working instead of metal removal. The barrel then was centerless ground to .0005 in. tolerance.

In order to lock the barrel assembly to the frame assembly after cocking, two sliding locks have been provided inside the frame guided on the cocking lever pin and the trigger pin (Exhibit 9). The two locks are urged by small springs into engagement with a cam on the sear bracket. The latter is silver brazed to the cylinder assembly. The locks can be disengaged by a button protruding thru the frame. All parts are made of stampings.

The cocking catch shown in Exhibit 12 was made of a U shaped stamping. This was provided with two lateral extensions at right angles to the plane of the drawing, preventing the catch from falling out of the slot. For assembly purposes the breech end of the slot is enlarged slightly more than the lateral extensions.

Considerable work went into developing the proper shape for the breech. Exhibit 10 shows the shape of a standard .22 caliber pellet. The size of the head is made to fit the bore, that is the top of the rifling lands. The trailing skirt is somewhat larger than the bottom of the rifling grooves. The chamber into which the pellet drops must be shaped so that the pellet will not start moving until after the air pressure is built up, otherwise too much air will be lost after the pellet leaves the muzzle. On

the other hand if the initial resistance of the pellet is too high, the leakage losses due to increased air pressure will be too great.

Note that in all spring guns the pellet acts as a valve which opens at a more or less fixed air pressure. Pump guns, on the other hand, must have a distinct valve, operated by the trigger directly or indirectly. This is also the case with the CO<sub>2</sub> guns.

The rearward acceleration of the piston during firing causes a forward acting reaction on the spring housing. This results in a downward dip of the pistol, followed by an upward motion when the piston hits home. Since the pellet cannot start moving until after the piston builds up enough air pressure, that is near its rearmost position, the pellet will leave the barrel while it is still pointed downward. This must be corrected by a parallax between barrel axis and line of sight between front and rear sights. (Exhibit 12) In fact the barrel is aimed well above the target before shooting although the sights are aimed directly at it. This is characteristic of all spring guns with rearward acting pistons while in those with forward action, like Diana and Haenel, the opposite is true.

### *Performance*

The two essential points in an air gun are its power and its accuracy. I measured the power, that is its muzzle velocity, by shooting the pellet, with the gun clamped in a stand, thru the periphery of two rapidly rotating paper discs set twelve inches apart, mounted on a common shaft. Knowing the rotational velocity one only has to measure the angle between the two points where the pellet nicks the two paper discs, in order to calculate the time spent in passing thru 12 in. distance.

Measured in this manner we did obtain approximately 300 and 400 ft. sec velocity respectively for the two calibers. Another more informal test is to fire the pellets against a steel plate and measure the amount of pellet flattening with a micrometer. This gives a quick relative comparison.

For accuracy tests the pistols are shot from a test stand against a target 30 feet away. A grouping of one inch diameter is considered acceptable. This may not sound very accurate, but one must bear in mind that commercial pellets are made of soft lead and are usually bulk packed. Hence they are out of round as well as subject to dents, etc. which affect their accuracy. If the pellets are selected (and today high precision match pellets are available) the results are better.

As to the overall mechanical efficiency of these guns, calculated as kinetic energy of pellet over potential spring energy, this comes to around 25%. The losses are partly frictional, partly leakage losses.

Occasionally when the gun is freshly oiled, after the excess oil has been expelled, the slight amount remaining in the air cylinder explodes due to compression heat, giving rise to much higher muzzle velocity. This suggests the possible development of a Diesel type gun, provided a simple scheme can be devised to accurately meter the fuel. Properly speaking this would bring these guns into the category of firearms and not pure air guns.

### *General*

We had no difficulty in obtaining patents on all salient features of the gun; however, we found the British patents costly.\* In England the law requires an annual fee for maintaining patents. At no time were we challenged in our patent rights or infringed in any way. People will try to copy you only if the ratio of possible commercial gain to the amount of investment required is high, which was not true in this case.

In rereading what I have written so far, I feel that it gives the misleading impression that during the design and production of the pistol everything always went as planned. Nothing could be further from the truth. Aside from a number of false starts and blind alleys, along about 1942 the War Production Board cut off our raw material sources, air guns being considered non essential to the war effort, which they were. We were of course forced into war production. At the end we were permitted to proceed. Thus it took about five years from conception to marketing.

In conclusion it was personally a rather satisfying experience to lead through an idea starting from its conceptual phase all the way to its manufacturing stage.

\*The reader may wish to refer to patents No. 2,601,033 and 2,633,839.

**EXHIBITS FOR ECL 134**

1. Diana Pistol
2. Haenel Pistol
3. Zenit Pistol
4. Webley Pistol
5. Hy Score Pistol
6. Breech Mechanism
7. Trigger Mechanism
8. Housing and Muzzle Assembly
9. Sliding Lock Assembly
10. .22 Caliber Pellet
11. Muzzle and Barrel Assembly
12. Hy Score Pistol Assembly

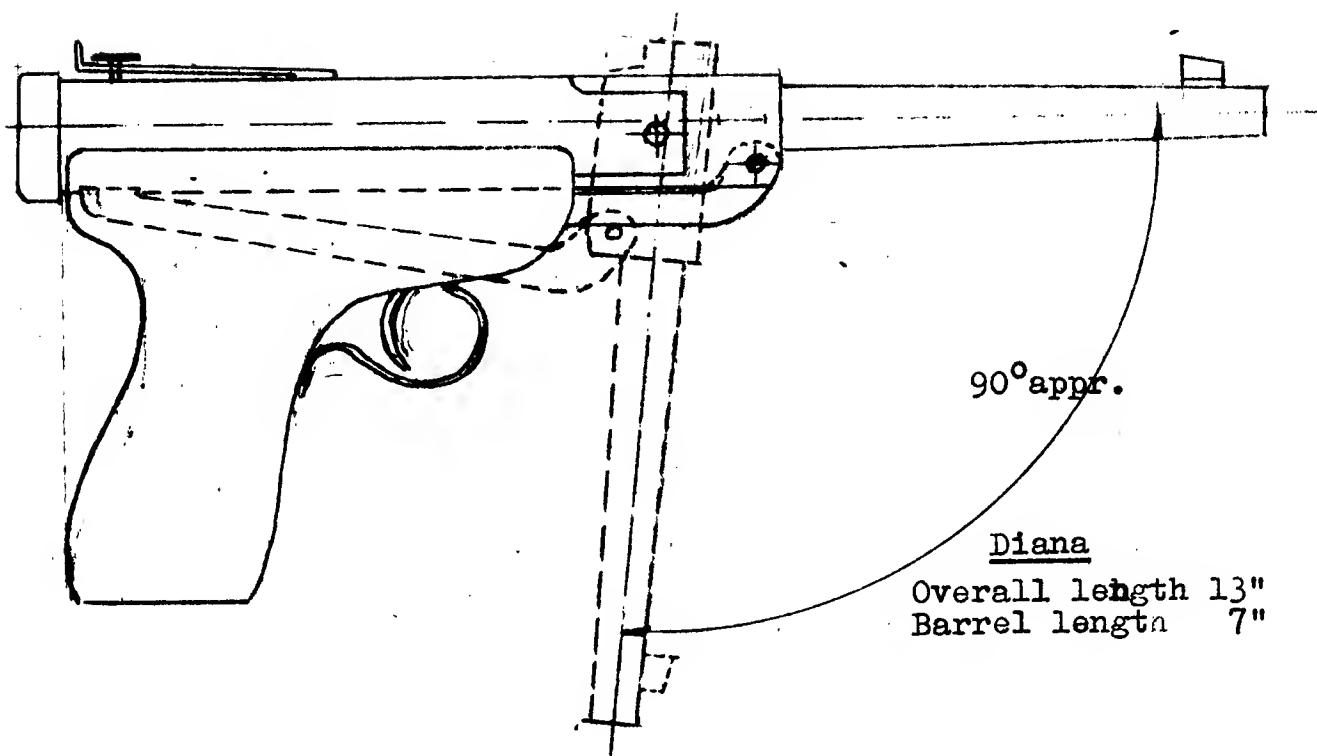


Exhibit 1. Diana Pistol

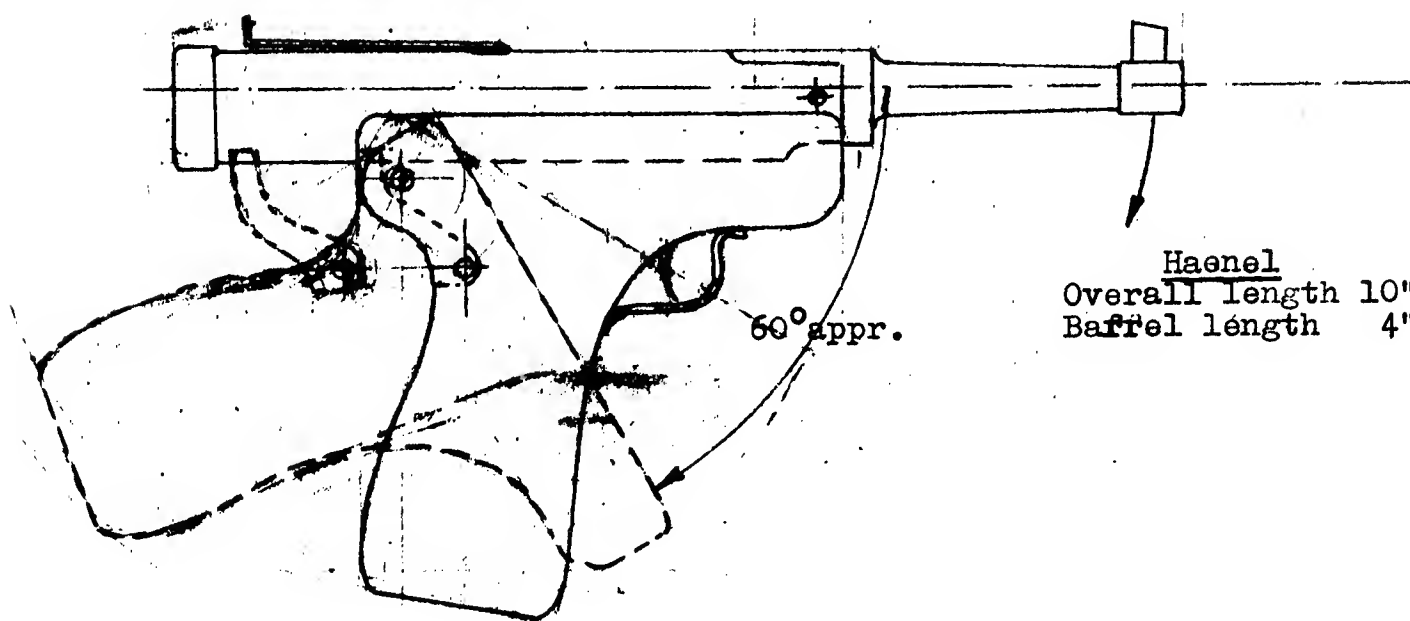


Exhibit 2. Haenel Pistol

110° approx

ECL 134

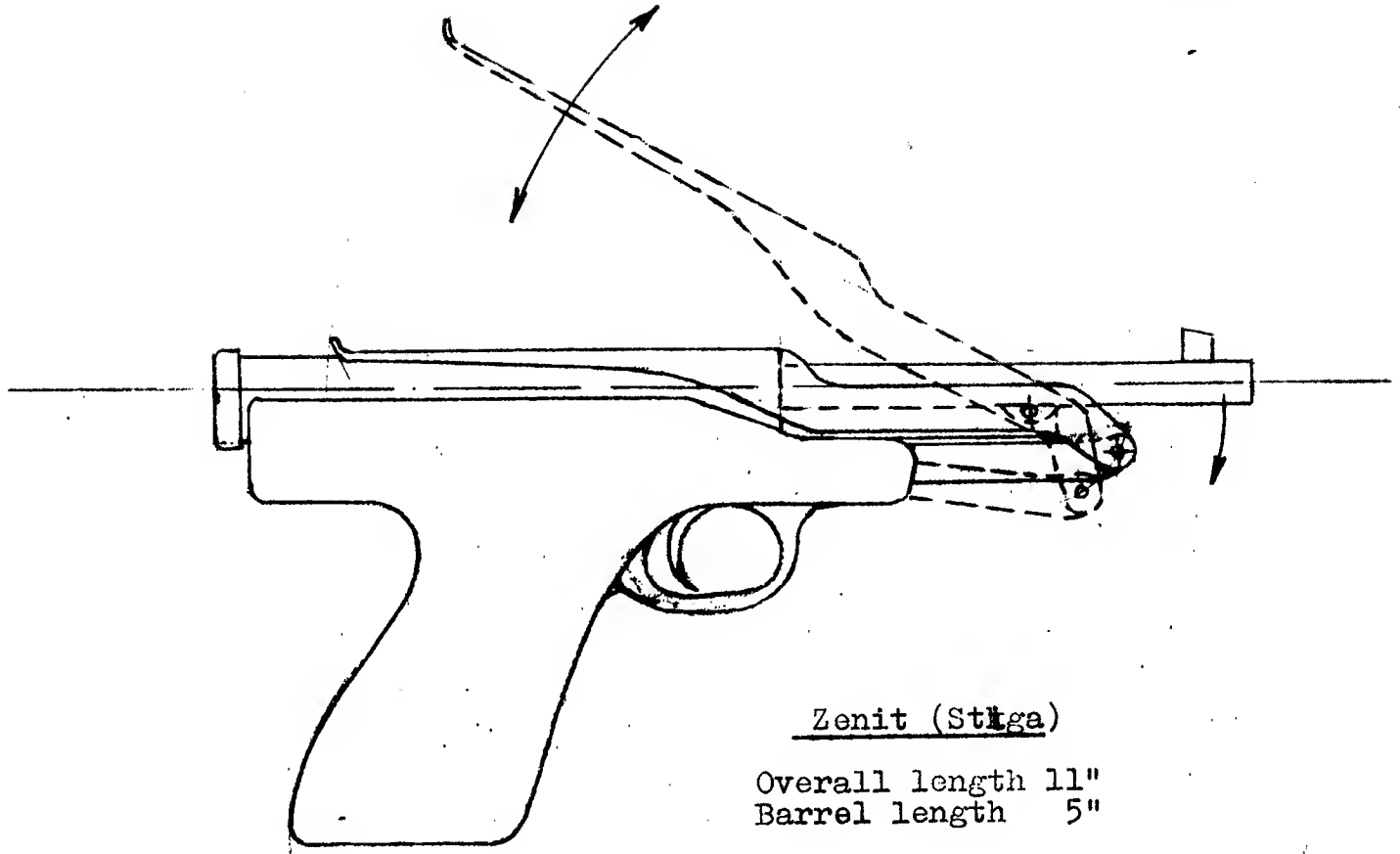


Exhibit 3. Zenit Pistol

160° appr.

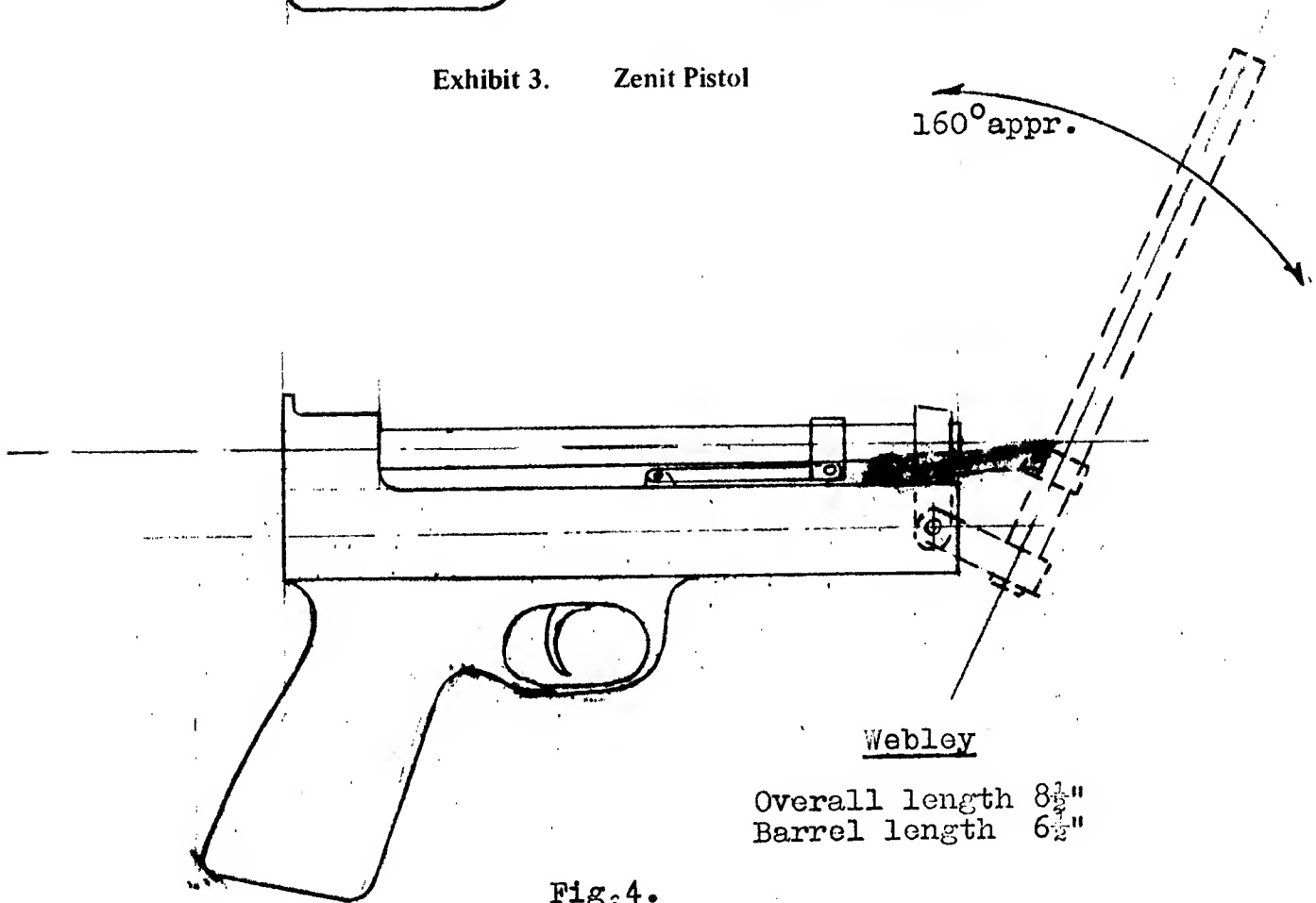
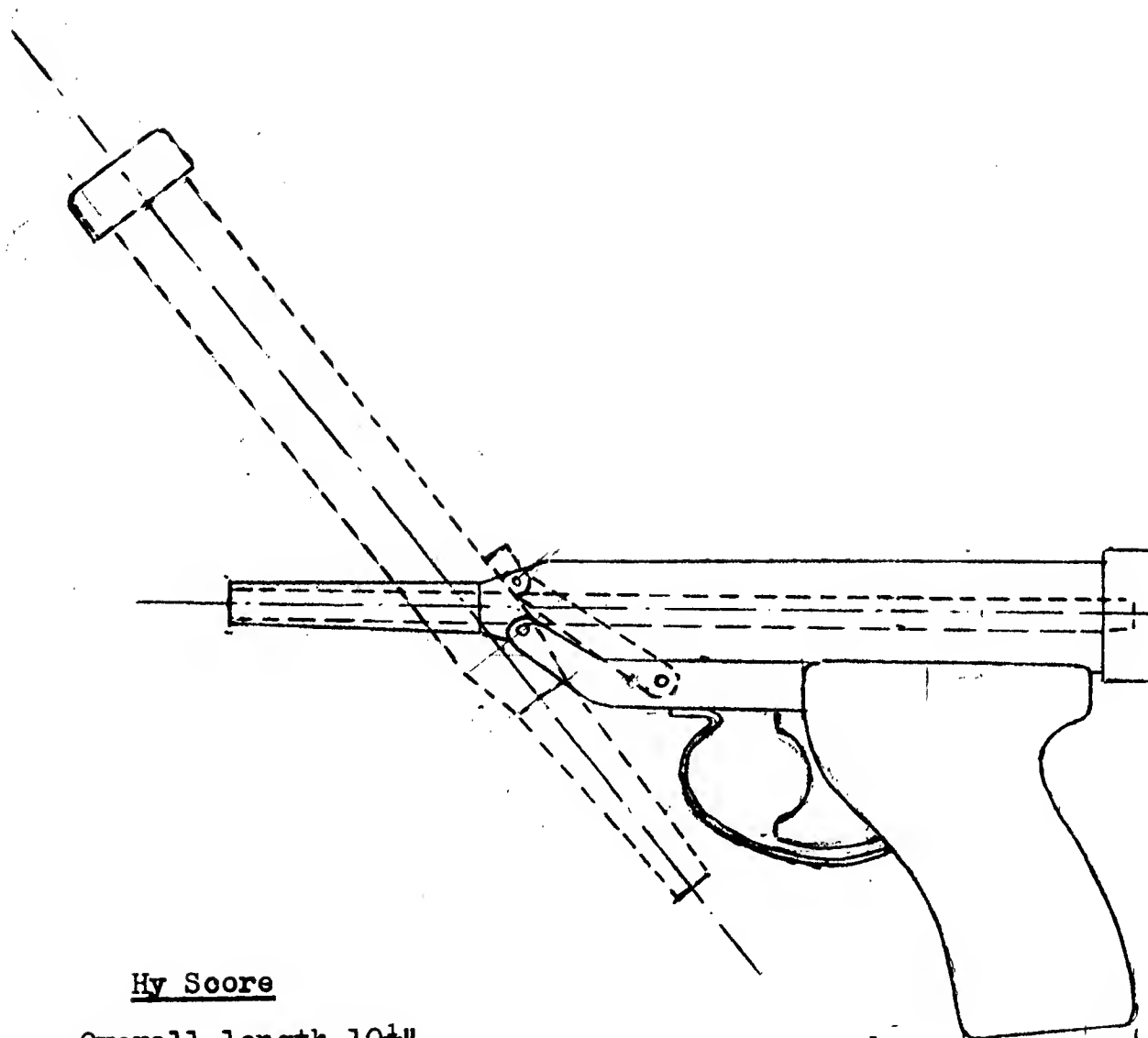


Fig. 4.

Exhibit 4. Webley Pistol



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Overall length  $10\frac{1}{2}$ "  
Barrel length 10"

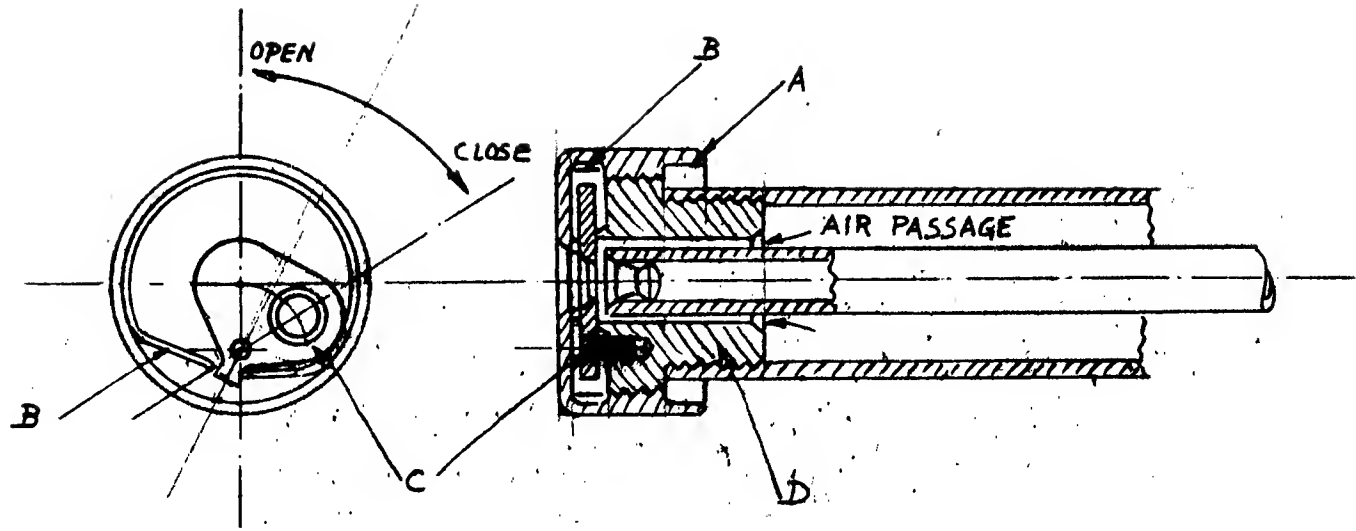


Exhibit 6. Breech Mechanism

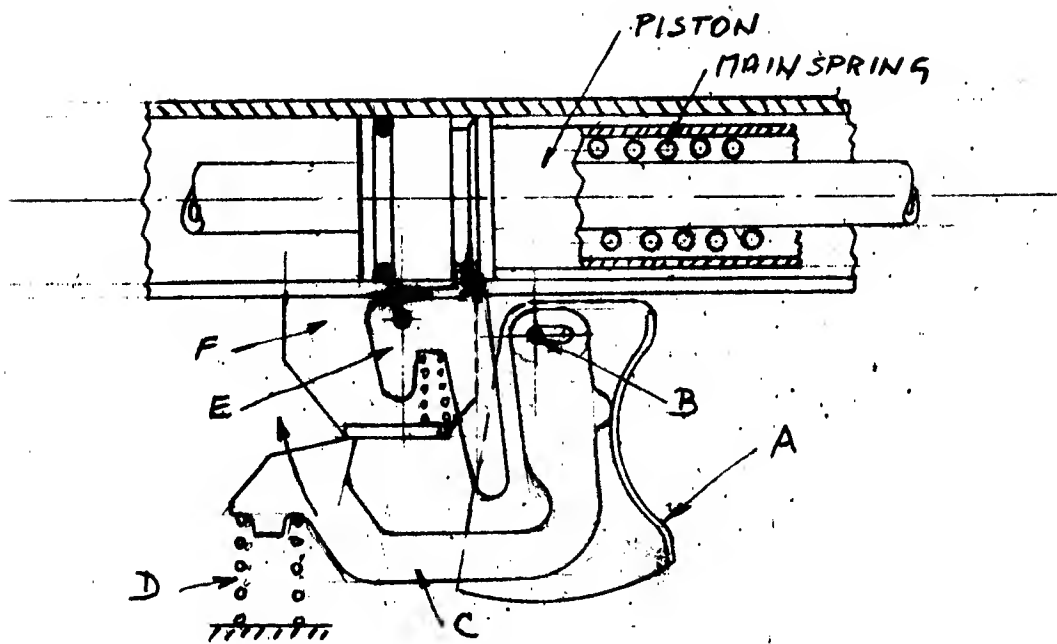


Exhibit 7. Trigger Mechanism

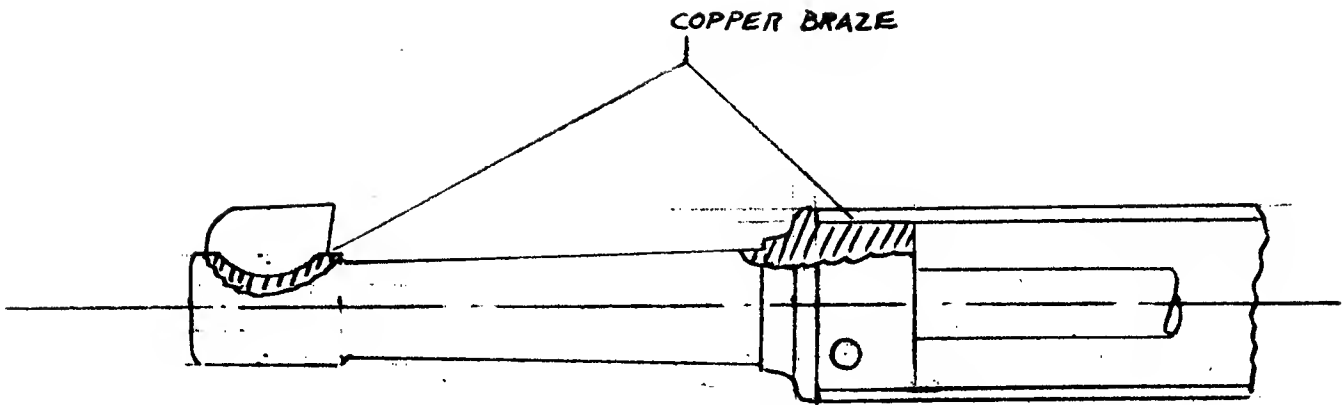


Exhibit 8. Housing and Muzzle Assembly

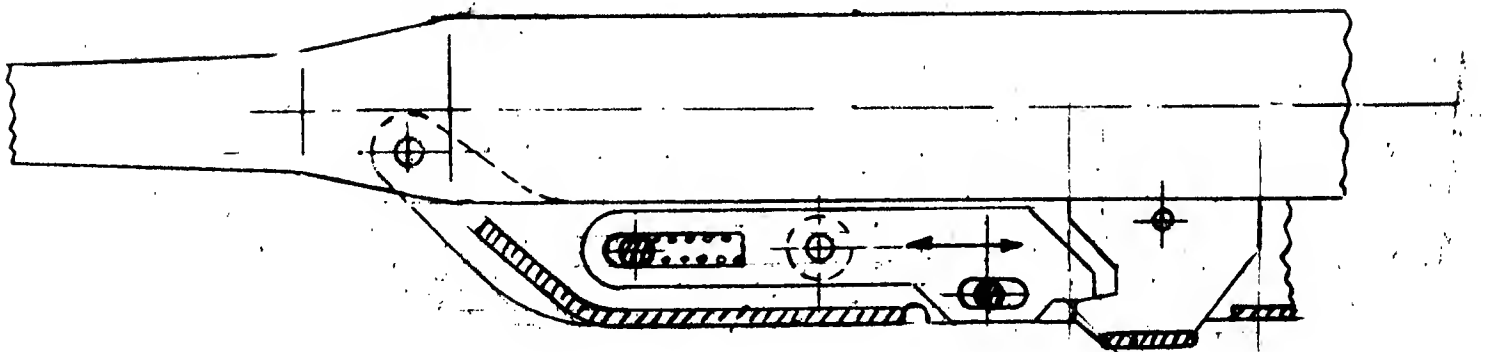


Exhibit 9. Sliding Lock Assembly

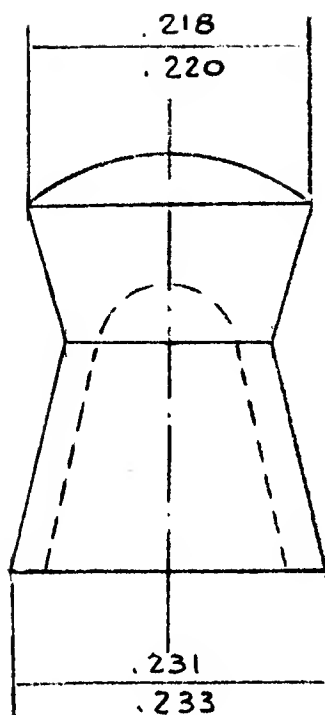


Exhibit 10. .22 Caliber Pellet

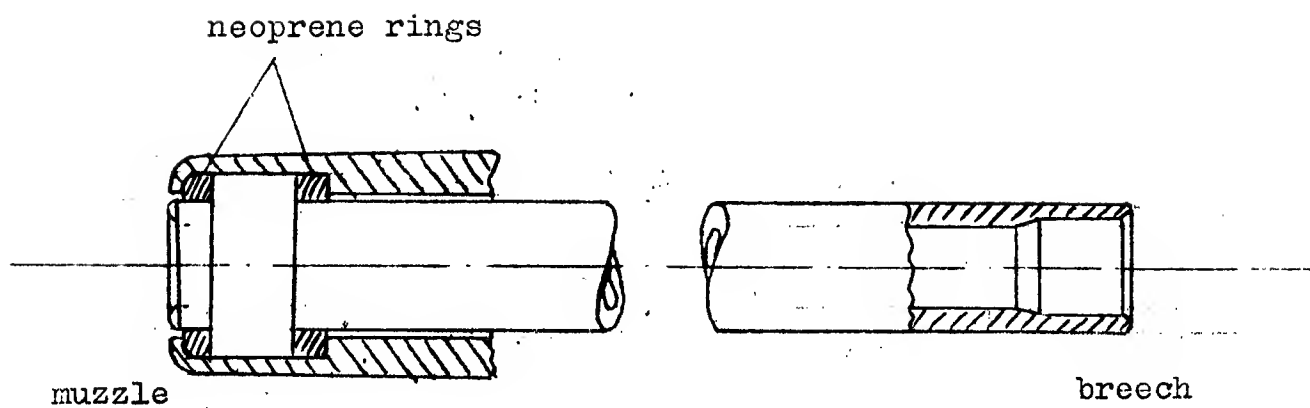


Exhibit 11. Muzzle and Barrel Assembly

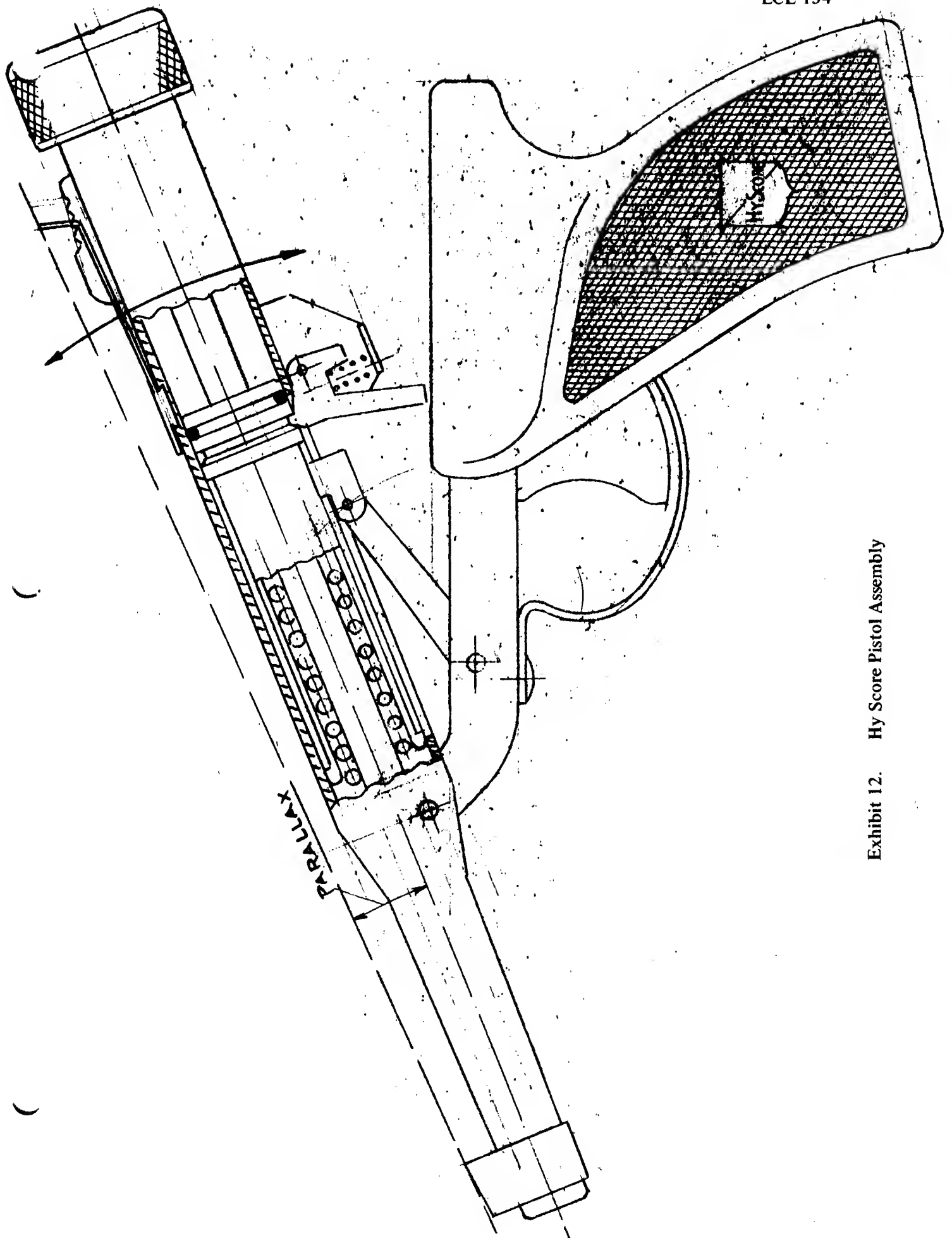


Exhibit 12. Hy Score Pistol Assembly

## INSTRUCTOR'S NOTE

This case history can be used as a basis for many exercises in design—ranging from detailed drawings to basic analysis. A few examples are given below:

**Detail design:** The piston, the housing in which the piston operates, and the parts which make up the breech (shown in Exhibit 7), will all require some judgment and decisions in detailing. A good detail drawing for any one of these would require several hours of student time.

**Materials and processes:** The choice of materials and the processing plan for any one of the several parts of this air pistol are suitable realistic exercises.

**Analysis:** With the muzzle velocity of 300 ft/sec and the dimensions of the pellet the kinetic energy delivered to the pellet is determined with the efficiency of 25% quoted in the case the potential energy in the spring can be calculated. The "stroke" of the spring can be scaled from Exhibit 12. The design of the spring then becomes an interesting exercise because the free length may be chosen longer than the extended

length of the spring in the pistol. The objective of the design will be to store as much potential energy as possible without exceeding a permissible stress in the spring. Analysis of the forces required to cock the pistol leads into the analysis of the linkage.

The recoil and downward dip mentioned in the case can be estimated quantitatively by applying the principles of dynamics.

A comparison of the efficiency of the spring operated air guns as compared with pump guns can be made by applying the principles of thermodynamics.

**Design:** With the hindsight provided by this case the student should be able to design an air pistol which either is equally good but simpler and less expensive or else easier to cock than the Hy Score air pistol. An iteration on the Webley design shown in Exhibit 4 would be one obvious approach to this design problem.